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DESIGN AND DEVELOPMENT OF OPTIMUM SABOT AMMUNITION FOR ARTILLERY WEAPONS

Progress Report No. 8
Contract No. DA1-28-017-501-ORD(P)-1531
Project No. TA1-5002

FC

AMERICAN MACHINE & FOUNDRY COMPANY

AUG 23 1955

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Contract No. DA1-28-017-501-ORD(P)-1531
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Period Covered - May 10, 1955 to June 9, 1955

Prepared for
Picatinny Arsenal
Dover, New Jersey

MR 1027

June 30, 1955

Copy No. 15

AMERICAN MACHINE & FOUNDRY COMPANY
1104 SOUTH WABASH AVENUE, CHICAGO 5, ILLINOIS

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DESIGN AND DEVELOPMENT OF OPTIMUM SABOT AMMUNITION FOR ARTILLERY WEAPONS

This is the eighth progress report (covering the period from May 10, 1955 to June 9, 1955) on "Design and Development of Optimum Sabot Ammunition for Artillery Weapons", prepared by the Mechanics Research Department, American Machine & Foundry Company for Picatinny Arsenal, Dover, New Jersey.

The AMF personnel who have contributed materially to this project include: A. Karbin, V. Milenkovic and P. Rosenberg. A breakdown of the number of man-hours expended is as follows:

Engineering	174 hours
Drafting	165 hours
	339 hours

Respectfully submitted,

AMERICAN MACHINE & FOUNDRY COMPANY
MECHANICS RESEARCH DEPARTMENT

V. Milenkovic

V. Milenkovic
Research Engineer

APPROVED:

P. Rosenberg

P. Rosenberg, Manager
Rockets & Missiles Group

I. INTRODUCTION

Sabot projectiles used in conventional guns offer a number of advantages over the standard full-caliber projectiles:

A. Higher probability of first-round hit, due to higher velocity and consequent shorter time of flight.

B. Possibility of greater armor penetration due to high striking velocity, i.e. to the kinetic energy concentrated in a smaller projectile area.

C. Interchangeability with standard rounds without alteration to the gun.

The objective of this contract is to develop the procedure leading to the design of Sabot Ammunition of optimum performance, to be used in various conventional guns in the 75mm to 280mm caliber range. The actual design will be carried out for the 90mm T-119 gun, but the procedure shall be applicable to the other guns mentioned.

II. REPORT ON DESIGN STUDIES

The up-to-date design, AMF No. 1027-31, of the 90/54mm HVAPDS projectile and sabot assembly is shown in Figure 1. This is the design planned for manufacture of projectiles to be used in full scale firing tests. Detailing of parts is in progress. According to the decisions reached at the meeting of June 7 at the Picatinny Arsenal (see Appendix A), this design will be carried out to the final test stage, if approved by the Arsenal, and if the critical components pass the static pressure test.

Projectile and Sabot Assembly. The WC penetrator (A), Figure 1, is brazed to the steel tail (B). The steel sleeve (C) and the aluminum sleeve (D) are screwed on, whereby the slotted spacer ring (G) is also held in place. In addition, sleeve (D) may be cemented to the carbide (A). Cementing the aluminum windshield tip (E) and screwing in the dummy tracer (F) completes the projectile assembly.

The nylon rotating band (N) is held on the aluminum driving cup (K) by threads. The magnesium front support tube (L) has a steel band (M) pressed on, which runs against the gun bore. The projectile is firmly locked in the carrier when the tube (L) is screwed into the cup (K), with the release ring (H) captured between the tube (L) and the projectile tail. The tail is seated in (K) at the conical surface. A seal ring (J) may be used to provide sealing until setback force produces a tight contact between (B) and (K). A rubber obturator (O) provides sealing at the gun bore.

<u>Operation.</u> During acceleration in the gun, the knurl at the conical surface of the tail will bite into the cup (K). Setback of the projectile will produce a clearance at the release ring (H), which due to both setback and centrifugal force will open up and clear the projectile. Sleeve (C) provides a shoulder to make the spacer ring (G) move out of the tube (L), when the projectile starts separating from the carrier. Once it is unrestrained by the tube, ring (G) can break up due to centrifugal force.

<u>Calculation of Weights and Moments.</u> Figure 2 shows a breakdown of the No. 1027-31 projectile into simpler components, in order to calculate weight, center of gravity, axial and transverse moments of inertia, all leading to the evaluation of the stability factor. The complete calculation is shown in Appendix B. Formulae applicable to some basic types of projectiles, developed in Report No. 4, served only as a guide in this projectile design. Due to the variety of shapes and materials used, each of the intermediate steps which lead to the present design required a detailed calculation by methods shown in Appendix B.

The weight of the projectile is 9.28 lbs., of which "penetration waste" (parts C, D, E, Figure 1) weigh 0.60 lbs. (6.5%). The carbide penetrator is 6.97 lbs., but 1.71 lbs. in back of the penetrator (B and F) are assumed to contribute to penetration. The stability factor is 1.50.

Only slightly more than half (57%) of the axial moment of inertia of the projectile is due to the carbide; stability depends to a large extent on steel parts of the projectile.

Details. Figure 3 shows the revised design of the carbide penetrator. It has a shorter and stubbier nose shape than the previous design (Figure 4a). It was found that the change in the penetrator nose has no effect on stability, so that it is not necessary or desirable to add weight to the windshield tip, as previously planned. Figures 4c, d, and e show some detail drawings, partially completed. Design and detailing of other component parts is in progress.

Hydraulic test fixture. Details of the pressure vessel components (Assembly of Figure 3, Report No. 7) are shown here in Figure 5, on which preliminary bids from manufacturers have been obtained. These details have been superseded by the new design (Figure 7), since it was decided to modify the length of the chamber, for reasons explained in Appendix A. Figure 6 shows the detail of the exterior loading frame.

The high pressure (up to 50,000 psi) in the vessel will be produced by an external load applied to a piston, which will act as a booster. Hydraulic equipment to produce the external load is available. Design work on the pressure vessel components and on the parts to be tested is in progress.

III. FUTURE PLANS

Completion of design, detailing, and manufacture of the static test fixture.

Completion of design and detailing of the 90/54mm projectile with sabot.

Static testing of critical components of the sabot.

Manufacture of about 20 projectiles for firing tests.

APPENDIX A

Report of Meeting, June 7, 1955,
at Picatinny Arsenal, Dover, New Jersey

Attending:	S. Jacobson	Picatinny Arsenal
	P. Rosenberg	American Machine & Foundry Co.
	V. Milenkovic	" " "

The purpose of the meeting was to discuss the status of the project and to plan future work.

To review briefly the objectives of the work done to date:

1. An analytical scheme for optimizing the design of spin stabilized HVAPDS has been presented.
2. Based upon this scheme, a design has been evolved for the 90mm T119 gun - the 90/54mm HVAPDS, AMF No. 1027-31.
3. It has been recommended by AMF that static tests be made of the rear components, and that a subsequent firing program be performed to demonstrate the suitability of the theoretical approach. This would be done,
   a. by predicting the ballistic limits on the basis of scale model tests currently being conducted at W.A.L., and comparing with test results of full scale firings;
   b. by comparing the performance of the test item with that of projectiles which have resulted from a long period of development.

It is not necessary that the performance of the AMF projectile be better than any of the presently used projectiles; it is only necessary to show that the performance is nearly comparable, for the following reasons:

The number of possible variables in projectile design being quite large, the theoretical work has not exhausted all possibilities in HVAPDS projectiles. Theoretical advantages of one design over another among the types analyzed were found to be marginal. The order of magnitude of factors not accounted for in this theory (factors which can be evaluated only by actual test) is such that no claim can be made that the present AMF design is superior to other HVAPDS designs. In particular, this design is not claimed to be competitive with other types of armor piercing projectiles, such as fin stabilized arrow projectiles fired from smooth bore guns.

The merit of the theoretical approach lies in helping to establish a basic projectile to which marginal improvements can then be made.

Conclusions:

1. It has been agreed to proceed with the present design (MR No. 1027-31), and upon approval of the Arsenal to manufacture a sufficient number of projectiles for firing tests (for performance in flight as well as for armor penetration). These tests will serve to prove or disprove the underlying theory, as well as to contribute to the empirical knowledge about the performance of various types of armor piercing projectiles.

2. Exterior performance of the projectile is considered to be the main objective of a firing test. Therefore, it is essential that the sabot carrier should not fail inside the gun. To minimize the risk of launching failure of a projectile which otherwise may have been successful, the planned static pressure test of critical components of the carrier should be completed. This static test will duplicate the forces acting in the gun as closely as possible. The difference in loading rate between the static test and actual firing will make the static test conservative. Such a test is considered more economical than a separate phase of firing to determine the strength of the carrier. It has been agreed to make the cavity in the hydraulic test fixture longer than previously planned, so that the Arsenal can make use of the fixture for other tests in the future.

3. No work on high explosive discarding sabots (HEDS) shall be performed under the project.

4. Funds which will be left over after the completion of the 90/54mm HVAPDS program shall be used in an analysis of long spinning projectiles, shape stabilized (conical tail).

APPENDIX B

Weights and Moments. The AMF No. 1027-31 projectile is broken down into several cylindrical or conical segments as shown in Figure 2.

For a hollow cylinder of outsider radius R, inside radius r, and height h:

Volume: $h(R^2 - r^2)\pi$

Axial radius of gyration: $r_x^2 = \frac{1}{2}(R^2 + r^2)$

Transverse radius of gyration about centroidal plane: $r_t^2 = h^2/12$

Axial moment of inertia: $A = I_x = Wr_x^2$ (W = weight)

Transverse moment of inertia about a point at distance x from the centroid: $B = \frac{1}{2} I_x + I_g$;* where $I_g = Wr_g^2$; $r_g^2 = r_t^2 + x^2$

For a truncated cone of large radius R, small radius r, and height h:

Volume: $\frac{h}{3} \frac{R^3 - r^3}{R - r} \pi$

Location of centroid from large end:

$$\frac{h}{2} - \frac{h}{4} \frac{(R - r)(R^2 - r^2)}{R^3 - r^3} \quad \left(\text{for full cone: } \frac{h}{4}\right)$$

$$r_x^2 = \frac{3}{10} \frac{R^5 - r^5}{R^3 - r^3}$$

r_t^2 is between $\frac{1}{12} h^2$ (when $R = r$) and $\frac{3}{80} h^2$ (when $r = 0$)

exactly: $r_t^2 = \frac{3}{80} h^2 \left[1 + \frac{R - r}{R^3 - r^3} Rr \left(2 + 5 \frac{R - r}{R^3 - r^3} Rr\right)\right]$

* For bodies of revolution, the polar moment (B) about the main centroidal axis GG is the sum of half the polar moment about the axis of revolution xx, and the second moment (I_g) about the transverse plane through the C.G. The latter is the sum of the moment about a plane through an individual centroid $G(Wr_t^2)$, and the transfer term (Wx^2).

WC Core (.520 lb/in^3)

1. Cylinder: $R = .850"$; $h = 4.410"$

$R^2 = .7225$; $R^2h = 3.187$

$W = 3.187 \cdot .520\pi = \underline{5.212 \text{ lbs}}$

$x = 0$; $M = Wx = \underline{0}$

$r_x{}^2 = \frac{1}{2} R^2 = .3612$; $I_x = Wr_x{}^2 = \underline{1.882 \text{ lb in}^2}$

$r_t{}^2 = h^2/12 = 1.620$; $x^2 = .000$

$r_g{}^2 = r_t{}^2 + x^2 = 1.620$; $I_g = Wr_g{}^2 = \underline{8.45 \text{ lb in}^2}$

2. Truncated cone: $R = .850"$; $r = .741"$; $h = .827"$

Location of centroid from large end:

$$\frac{h}{2} - \frac{h}{4} \frac{(R - r)(R^2 - r^2)}{R^3 - r^3} = .395"$$

Volume: $\frac{h}{3} \frac{R^3 - r^3}{R - r} \pi = .5245\pi$

$W = .5245 \cdot .520\pi = \underline{.857 \text{ lbs}}$

$x = 2.600$; $M = \underline{2.228 \text{ in lbs}}$

$r_x{}^2 = \frac{3}{10} \frac{R^5 - r^5}{R^3 - r^3} = .3185$; $I_x = \underline{.273 \text{ lb in}^2}$

$r_t{}^2 = h^2/12 = .057$; $x^2 = 6.760$

$r_g{}^2 = r_t{}^2 + x^2 = 6.817$; $I_g = \underline{5.84 \text{ lb in}^2}$

3. Truncated cone: $R = .741''$; $r = .495''$; $h = 1.328''$

Location of centroid from large end $.577''$

Volume $= .514\,\pi$

$W = .514 \cdot .520\,\pi = \underline{.835 \text{ lbs.}}$

$X = 3.609$; $\underline{M = 3.014 \text{ in lbs}}$

$r_x^2 = .204$; $I_x = \underline{.170 \text{ lb in}^2}$

$r_t^2 = .147$; $x^2 = 13.025$

$r_g^2 = 13.172$; $I_g = \underline{11.00 \text{ lb in}^2}$

4. Cone: $R = .495$; $h = .495$

Location of centroid; $h/4 = .124''$ from base

Volume $\frac{h}{3} \cdot R^2\pi = .0404\,\pi$

$W = .0404 \cdot .520\,\pi = \underline{.066 \text{ lb}}$

$x = 4.484$; $\underline{M = .296 \text{ in lbs}}$

$r_x^2 = \frac{3}{10} R^2 = .0735$; $I_x = \underline{.005 \text{ lb in}^2}$

$r_t^2 = \frac{3}{80} h^2 = .009$; $x^2 = 20.10$

$r_g^2 = 20.11$; $I_g = \underline{1.33 \text{ lb in}^2}$

	W	M	I_x	I_g
1	5.212	.000	1.882	8.45
2	.857	+2.228	.273	5.84
3	.835	+3.014	.170	11.00
4	.066	+ .296	.005	1.33
Total	6.970 lbs	+5.538 in lbs	2.330 lb in^2	26.62 lb in^2

<u>Steel Tail</u> (.283 lb/in^3)

5. Hollow cylinder: $R = 1.110"$; $r = .625"$; $h = 1.970"$

$R^2 = 1.2321$; $r^2 = .3906$; Vol: $h(R^2 - r^2)\ \pi = 1.658\ \pi$

$W = 1.658 \cdot .283\ \pi = \underline{1.477 \text{ lbs}}$

$x = -3.190$; $M = -3.190 \cdot 1.477 = \underline{-4.711 \text{ in. lbs}}$

$r_x^2 = \frac{1}{2}(R^2 + r^2) = .8113$; $I_x = 1.198$

$- 3\%$ correction $\underline{-.036^*} = \underline{1.162 \text{ lb in}^2}$

$r_t^2 = h^2/12 = .323$; $x^2 = 10.177$

$r_g^2 = r_t^2 + x^2 = 10.50$; $I_g = \underline{15.51 \text{ lb in}^2}$

6. Hollow cylinder: $R = .625"$; $r = .375"$; $h = .700"$

$R^2 = .3906$; $r^2 = .1406$; $h(R^2 - r^2) = .175$

$W = .175 \cdot .283\ \pi = \underline{.156 \text{ lb}}$

$x = -2.555$; $M = \underline{-.398 \text{ in lbs}}$

$r_x^2 = .2656$; $I_x = \underline{.041 \text{ lb in}^2}$

$r_t^2 = .041$; $x^2 = 6.528$; $r_g^2 = 6.569$; $I_g = 1.02 \text{ lb in}^2$

Total:	W	M	I_x	I_g
	1.633 lbs	- 5.109 in lbs	1.203 lb in^2	16.58 lb in^2

* To account for steps and chambers (see dotted lines in Figure 2)

Steel Sleeve (.283 lb/in^3)

7. Hollow cylinder: $R = 1.062"$; $r = .977"$; $h = 1.470"$

$R^2 = 1.1278$; $r^2 = .9545$; $h(R^2 - r^2) = .255$

$W = .255 \cdot .283\ \pi = \underline{.227 \text{ lbs}}$

$x = -1.690$; $M = -1.690 \cdot .227 = \underline{-.384 \text{ in lbs}}$

$r_x{}^2 = 1.041$; $I_x = \underline{.236 \text{ lb in}^2}$

$r_t{}^2 = .180$; $x^2 = 2.856$; $r_g{}^2 = 3.036$; $I_t = \underline{.69 \text{ lb in}^2}$

8. Hollow cylinder: $R = 1.054$; $r = .950$; $h = .875$

$R^2 = 1.1109$; $r^2 = .9025$; $h(R^2 - r^2) = .1825$

$W = .1825 \cdot .283\ \pi = \underline{.162 \text{ lbs}}$

$x = -.518$; $M = \underline{-.084 \text{ in lbs}}$

$r_x{}^2 = 1.007$; $I_x = \underline{.163 \text{ lb in}^2}$

$r_t{}^2 = .064$; $x^2 = .268$; $r_g{}^2 = .332$; $I_g = \underline{.05 \text{ lb in}^2}$

Total:	W	M	I_x	I_g
	.389 lbs	- .468 in lbs	.399 lb in^2	.74 lb in^2

Aluminum Sleeve (.0955 lb/in^3)

9. Hollow cylinder: $R = .963"$; $r = .850"$; $h = 2.750"$

$R^2 = .9275$; $r^2 = .7225$; $h(R^2 - r^2) = .564$

$W = .546 \cdot .0955\ \pi = \underline{.169 \text{ lbs}}$

$x = .420$; $M = .420 \cdot .169 = \underline{.071 \text{ in lbs}}$

$r_x{}^2 = \frac{1}{2}(R^2 + r^2) = .825$; $I_x = \underline{.140 \text{ lb in}^2}$

$r_t{}^2 = h^2/12 = .630$; $x^2 = .176$; $r_g{}^2 = .806$; $I_g = \underline{.14 \text{ lb in}^2}$

Aluminum nose

10. W = .037 lbs ; x = 5.075 ; M = .188 in lbs

neglect r_x, r_t; I_x = 0

$r_g^2 = x^2 = 25.8$; I_g = .95 lb in^2

Tracer

11. W = .082 lbs ; x = - 2.680 ; M = - .220 in lbs

neglect r_x, r_t; I_x = 0

$r_g^2 = x^2 = 7.18$; I_g = .59 lb in^2

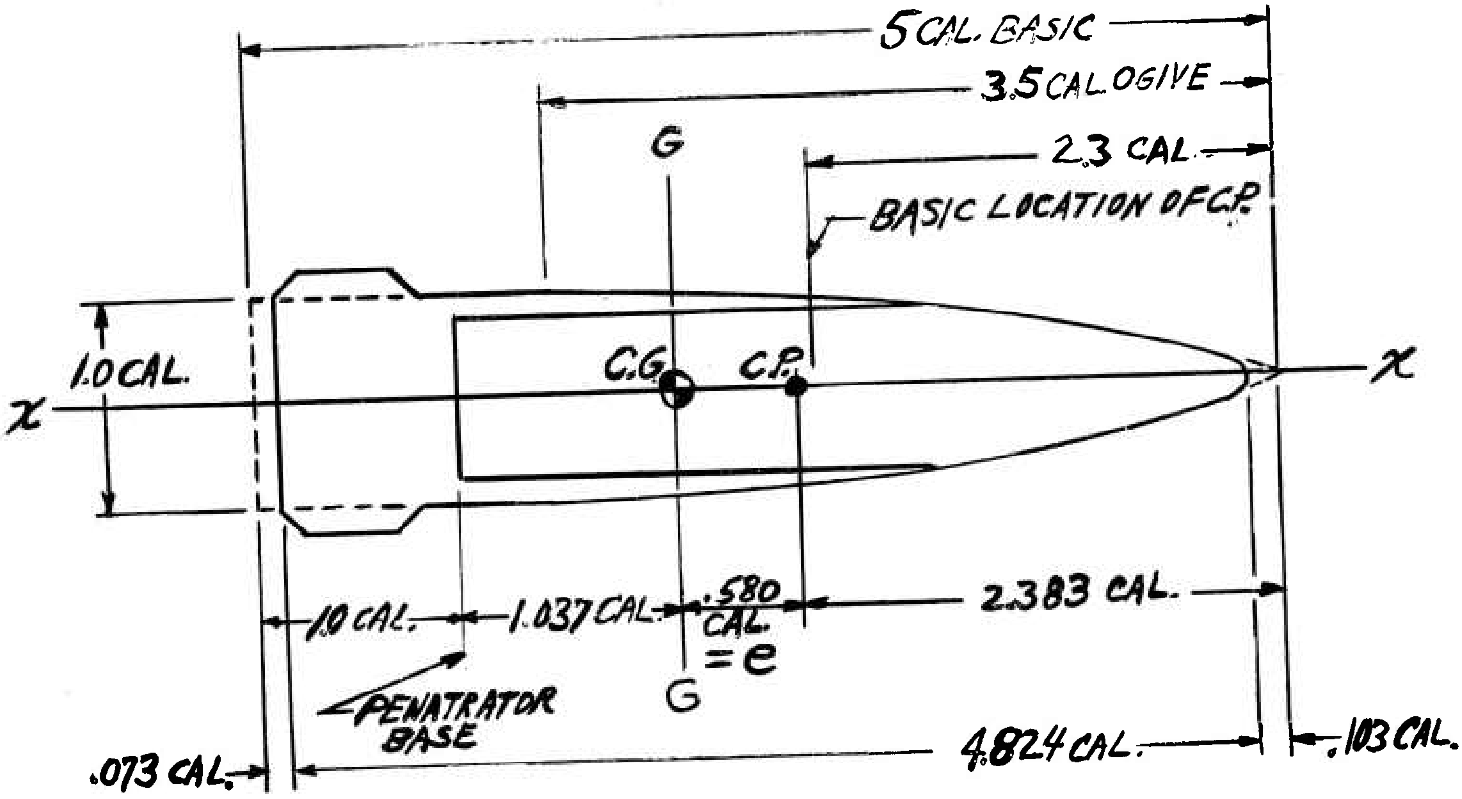
Projectile	W, lbs	M, in lbs −	M, in lbs +	I_x, lb in^2		I_g, lb in^2
WC Core	6.970		5.538	2.330		26.62
Steel Tail	1.633	5.109		1.203		16.58
Steel Sleeve	.389	.468		.399		.74
Alum. Sleeve	.169		.071	.140		.14
Alum. Nose	.037		.188	-		.95
Tracer	.082	.220		-		.59
Total	9.280	-5.797	+5.797	4.072		45.62
		0			+ $\frac{1}{2}$ I_x	2.04
						47.66

Stability

Nominal caliber: 2.125" = 54mm

Length: 10.25" = 4.824 cal

Location of C.G.: 2.205" = 1.037 cal. from penetrator base



The center of pressure (C.P.) for the basic 5 caliber long, 3.5 cal. ogive, above Mach 3.2, is located 2.3 cal. from the tip (see Report No. 6, Footnote 1 and Figure 1). The oversize base is assumed to move the C.P. .10 cal. back; the projectile is somewhat shorter than 5 cal., for which the C.P. correction is about .02 cal. forward (25% of .073). The resulting

C.P. to C.G. distance, as shown in the diagram above is:

$e = .580$ cal

Stability $S = \dfrac{A^2\,\omega^2}{4Be\,C_N'\,\frac{\rho}{2}\,\frac{\pi}{4}\,d^3\,V^2}$

$$= \frac{A^2}{2Be\,C_N^1\,(\frac{\pi}{4}\,d^3\rho)(\frac{V}{\omega})^2}$$

Axial polar moment of inertia (axis X-X): $A = 4.072$ lb in^2

Transverse polar moment of inertia about C.G. (axis G-G): $B = 47.66$ lb in^2

Normal force coefficient: $C_N' = \left(\dfrac{d\,C_N}{d\,\alpha}\right)_0 = 3.0$

Density of air: $\rho = .0765$ lb/ft^3 $= .0443 \cdot 10^{-3}$ lb/in^3

Diameter $d = 2.125"$

$$\frac{\pi}{4}\,d^3\rho = \frac{\pi}{4}\,(2.125)^3 \cdot .0443 \cdot 10^{-3} = .334 \cdot 10^{-3} \text{ lbs}$$

$$\frac{V}{\omega} = 25 \text{ dia/turn} = \frac{25 \cdot 3.54}{2\pi} = 14.1 \text{ inches/radian}$$

$$S = \frac{(4.072)^2 \cdot 10^3}{2 \cdot 47.66 \cdot .58 \cdot 3.0 \cdot .334 \cdot (14.1)^2} = 1.50$$

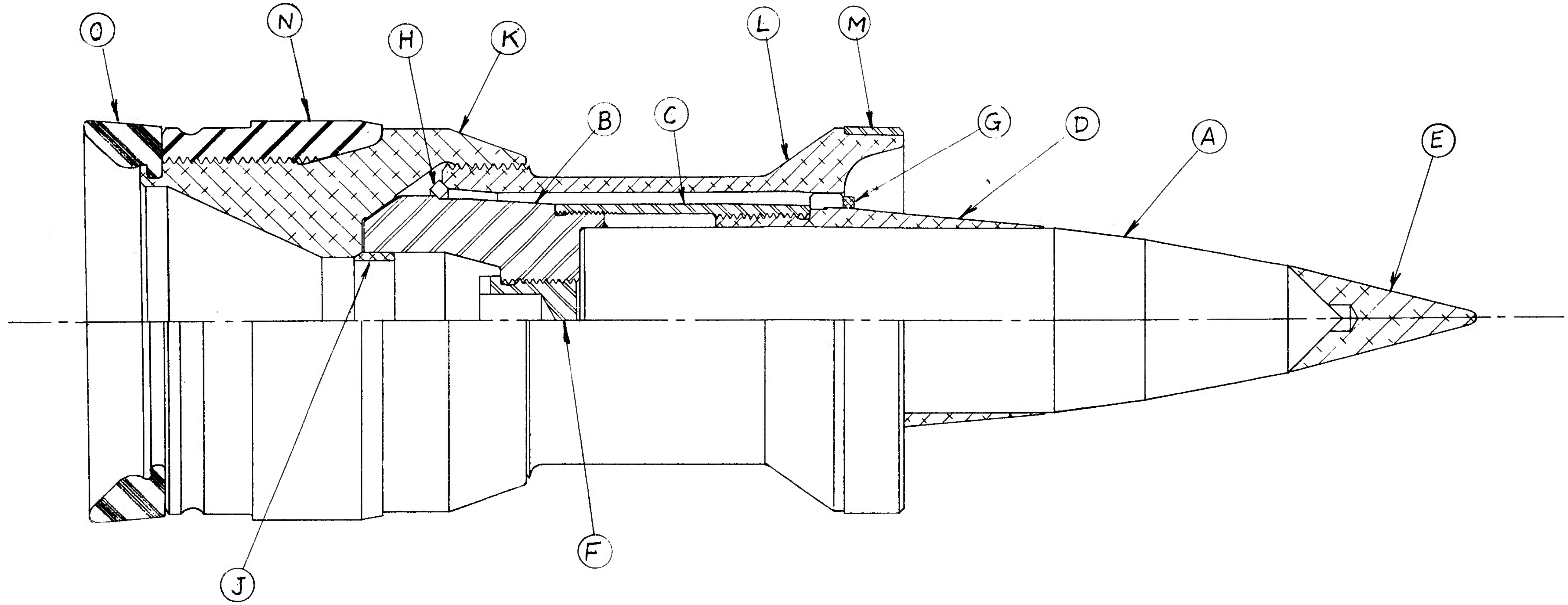


FIGURE 1.

PROJECTILE & SABOT ASSEMBLY OF
90/54 MM. HVAPDS - AMF No. 1027-31

PROJECTILE - TYPE: 1.70" CORE COMPOSITE - WEIGHT: 9.28 LBS
CARRIER - TYPE: ALUMINUM DRIVING CUP - WEIGHT: 2.35 LBS
WEIGHT AS FIRED: 10.63 LBS - MUZZLE VELOCITY: 4250 FT/SEC.

LET.	DATE	DESCRIPTION OF CHANGE	APPROVED
AMERICAN MACHINE & FOUNDRY CO.			
TRADE MARK	PART NAME		
SCALE: FULL	DRAWN BY	CHECKED BY	APPROVED BY	ENG. RELEASE NO.
DATE	6/9/55			
USED ON	NUMBER: 1027-31 SK-O			

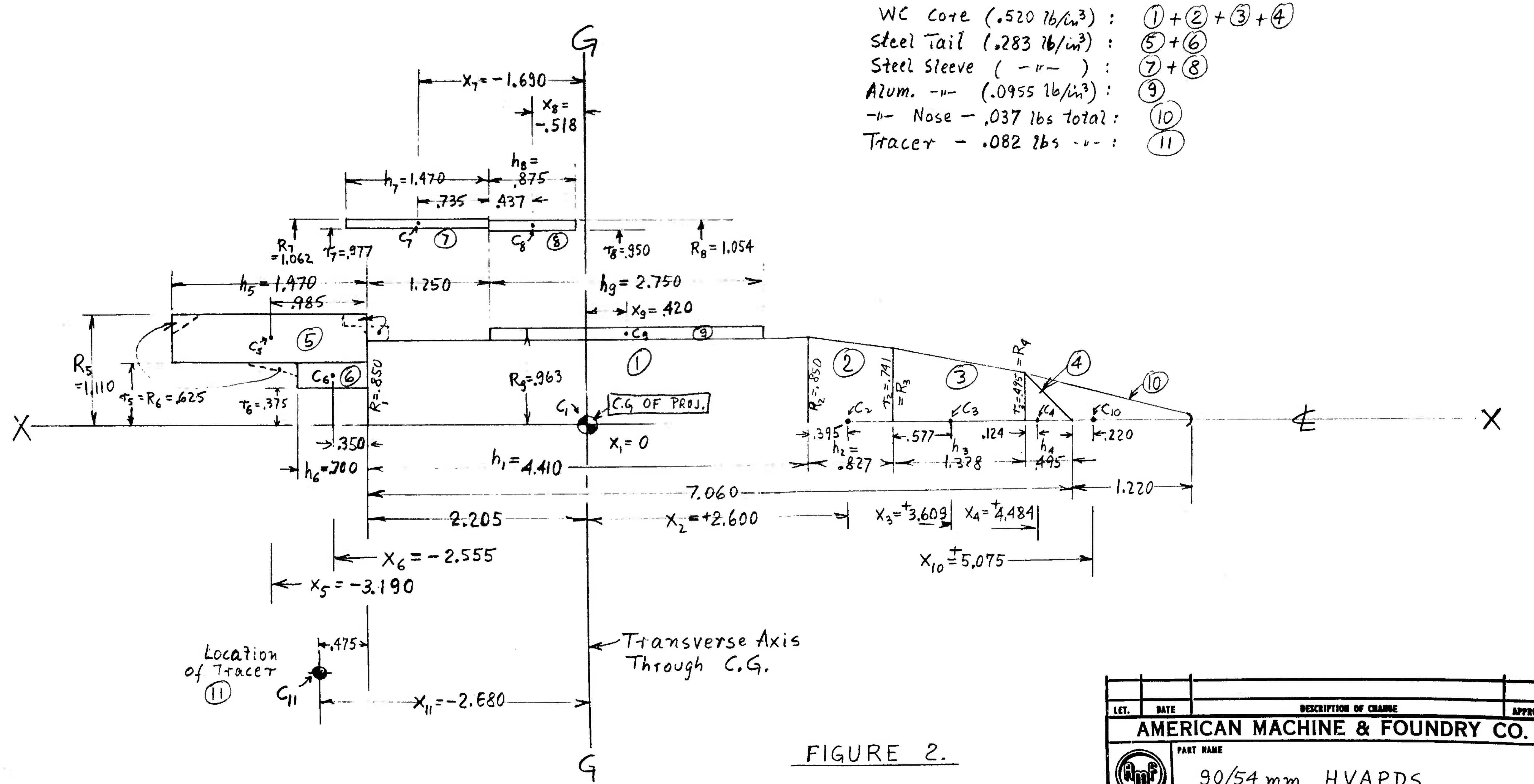


FIGURE 2.

No. 1027-31 PROJECTILE – BREAKDOWN FOR WEIGHTS & MOMENTS CALCULATION

LET.	DATE	DESCRIPTION OF CHANGE	APPROVED

AMERICAN MACHINE & FOUNDRY CO.

TRADE MARK

PART NAME: 90/54 mm HVAPDS

SCALE	DRAWN BY	CHECKED BY	APPROVED BY	ENG. RELEASE NO.
FULL				
DATE: 6/3/55				

USED ON | NUMBER

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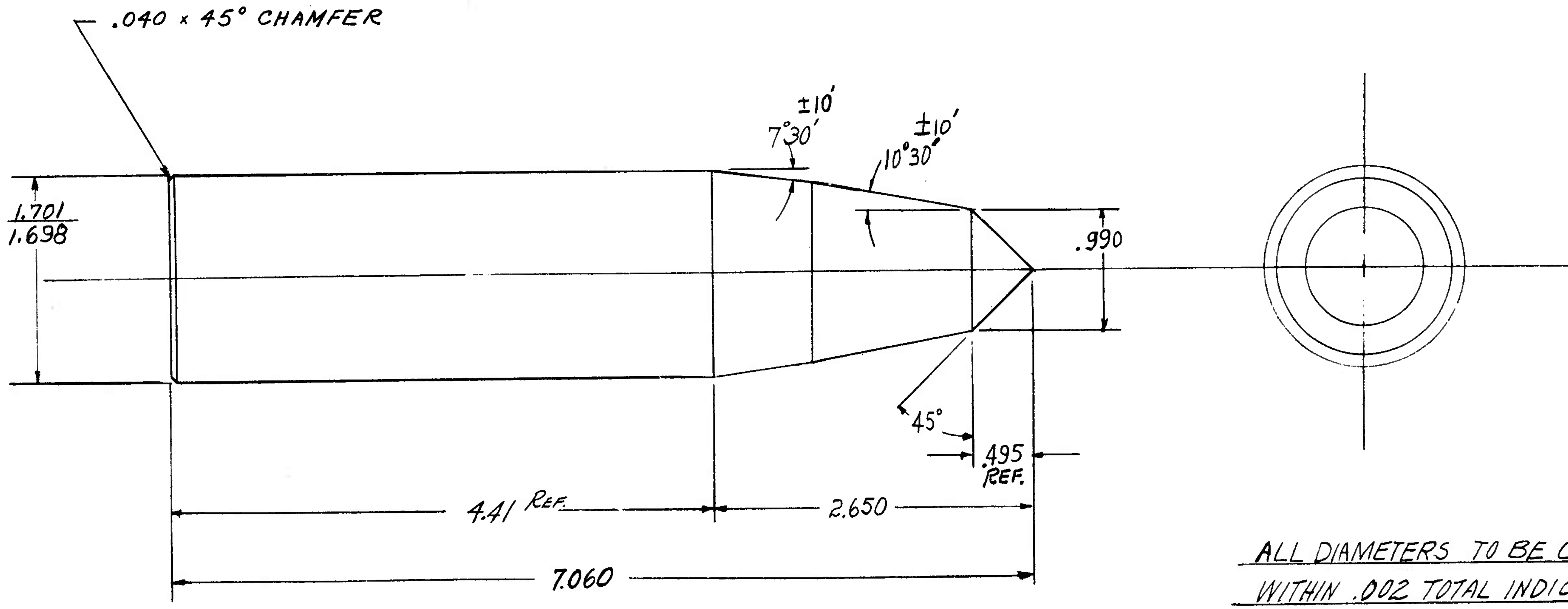

ALL DIAMETERS TO BE CONCENTRIC WITHIN .002 TOTAL INDICATOR READING

FIGURE 3.
FINAL PENETRATOR DESIGN FOR THE No. 1027-31 PROJECTILE

MATERIAL:
TUNGSTEN CARBIDE GRADE 120
SPECIFIC GRAVITY 14.3-14.4

UNLESS OTHERWISE SPECIFIED
0.0 EQUALS PLUS OR MINUS .100
0.00 EQUALS PLUS OR MINUS .015
0.000 EQUALS PLUS OR MINUS .005
ANGLES ± 1/4°

LET.	DATE	DESCRIPTION OF CHANGE	APPROVED

AMERICAN MACHINE & FOUNDRY CO.

TRADE MARK — PART NAME: PENETRATOR - WC

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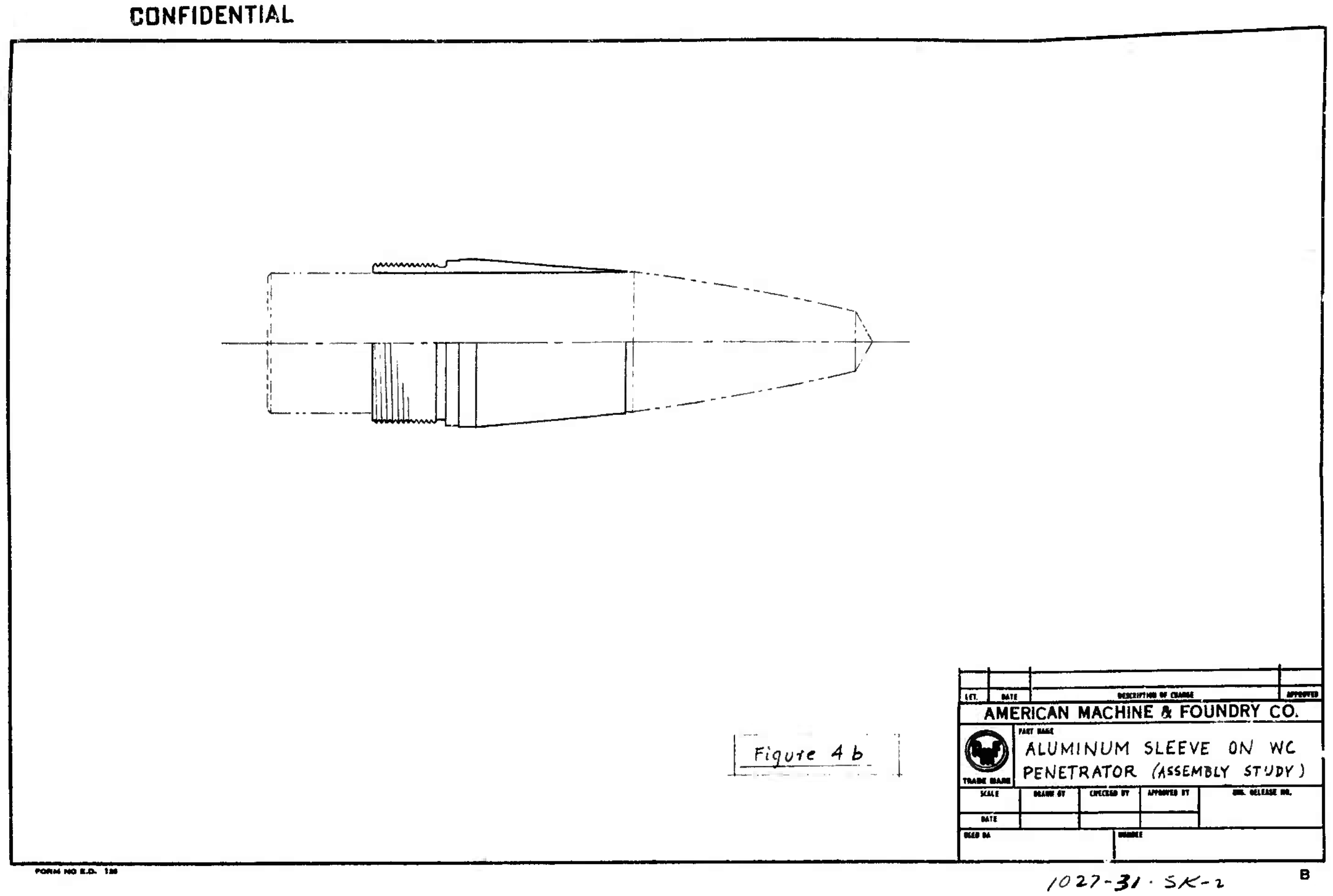

Figure 4b

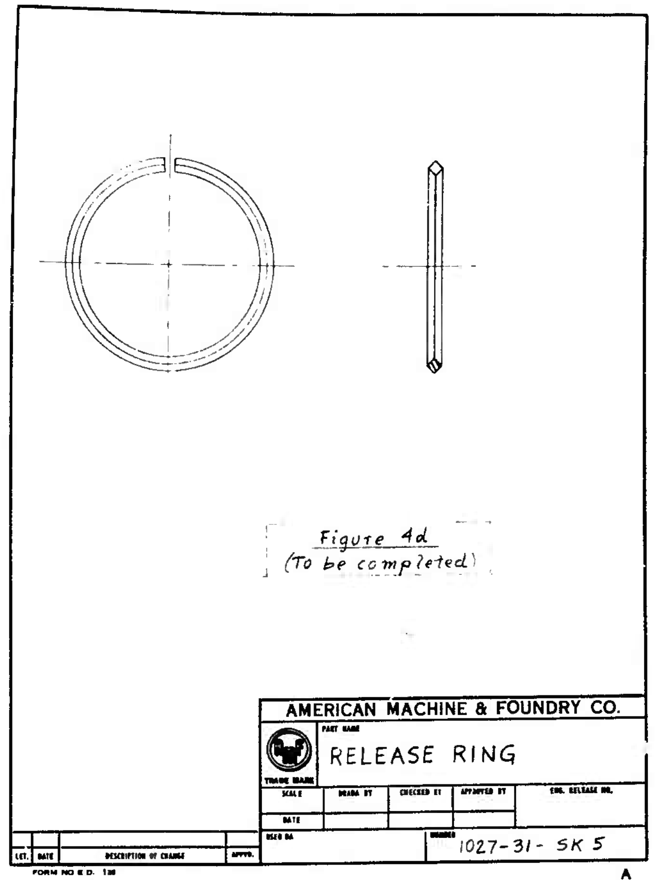

Figure 4d
(To be completed)

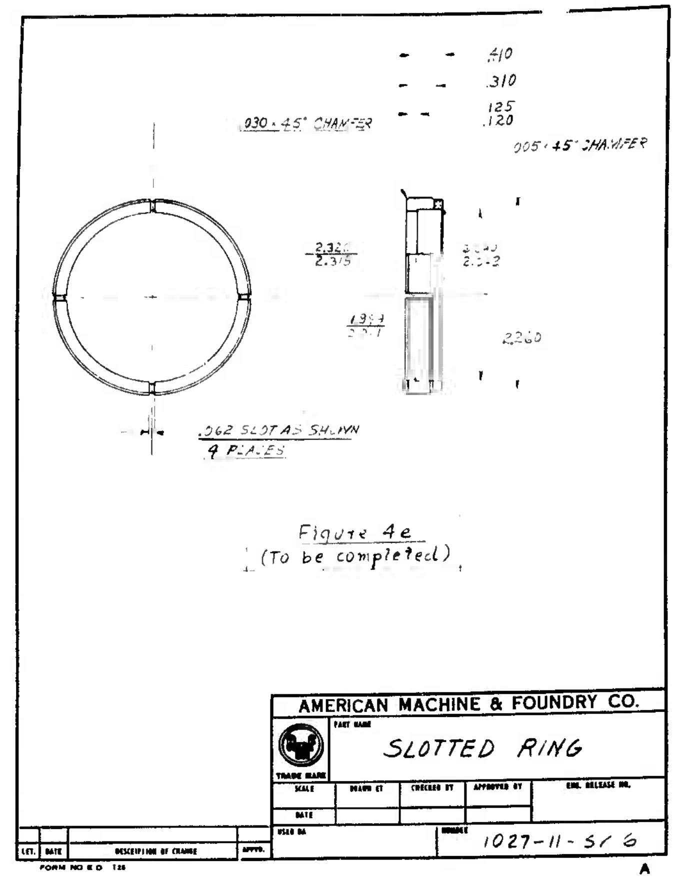

Figure 4e
(To be completed)

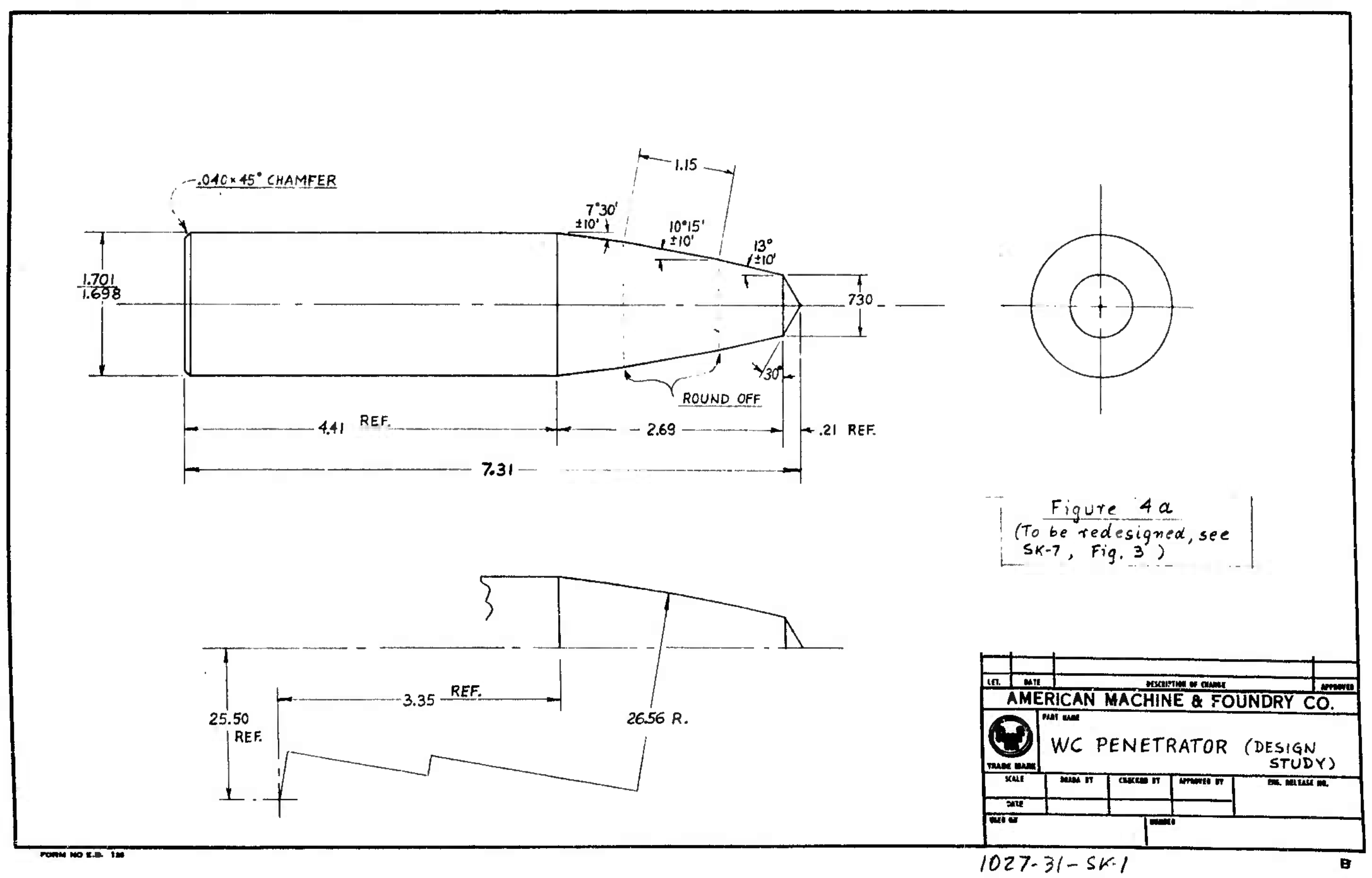

Figure 4a
(To be redesigned, see SK-7, Fig. 3)

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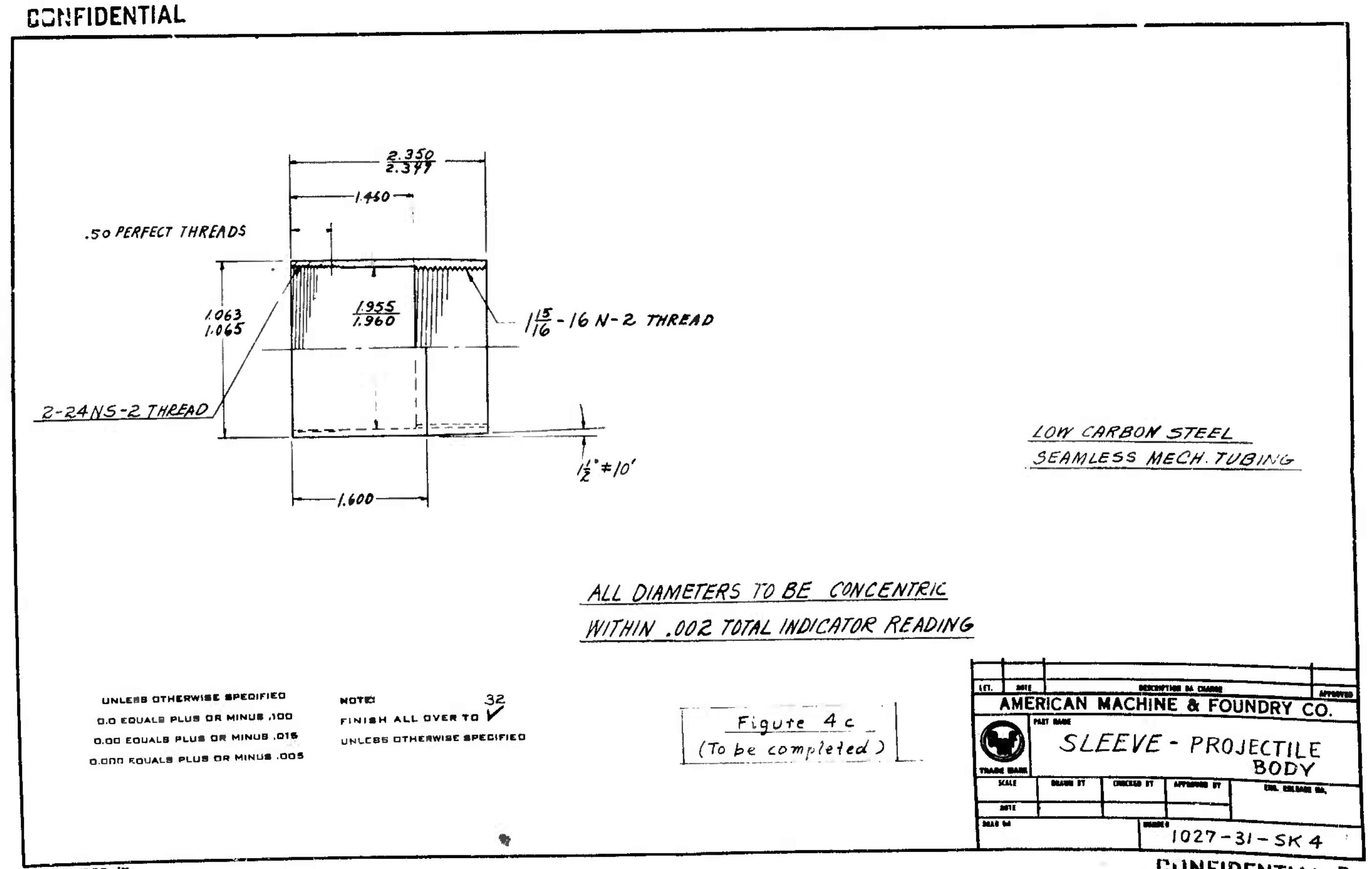

Figure 4c
(To be completed)

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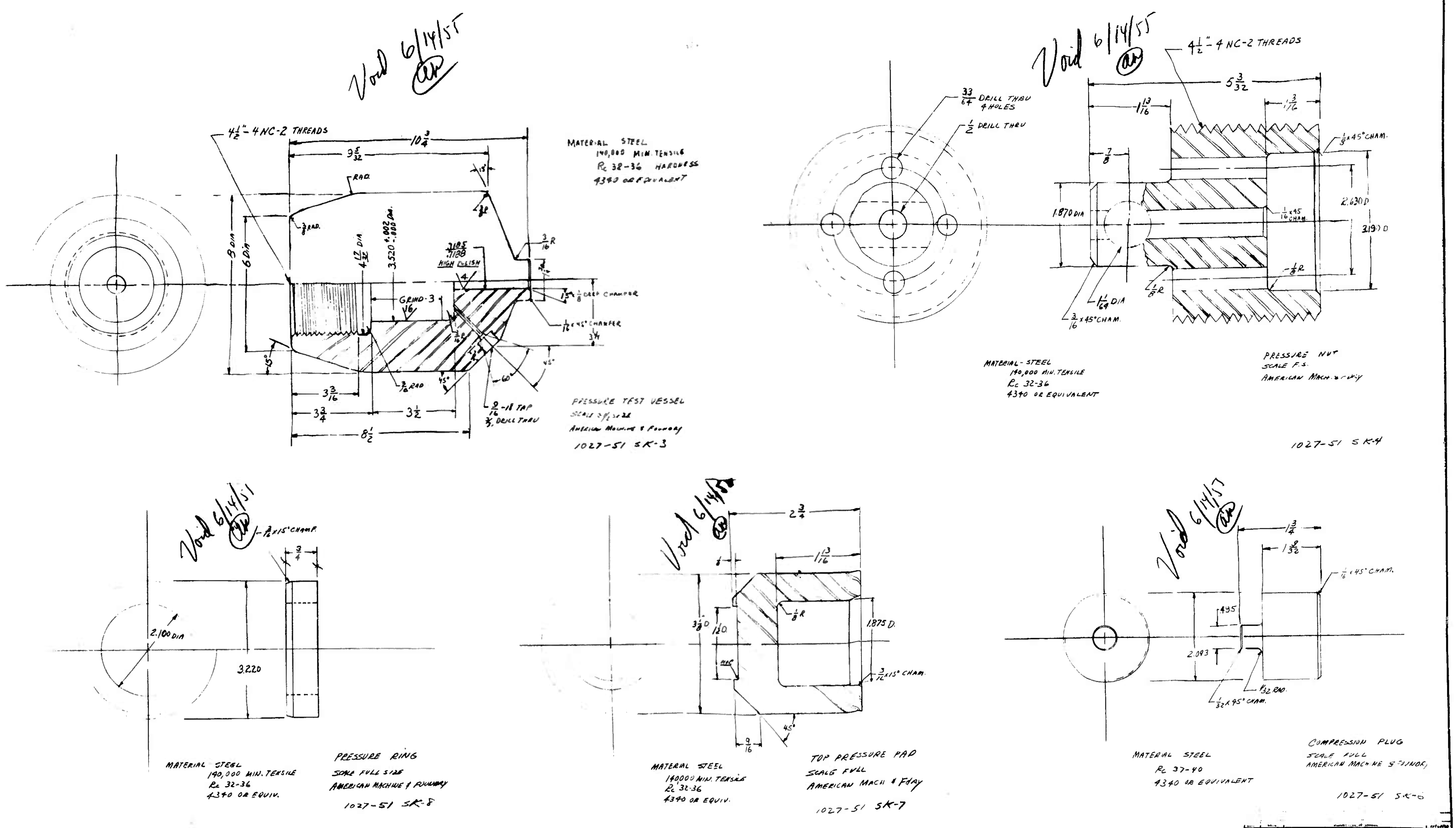
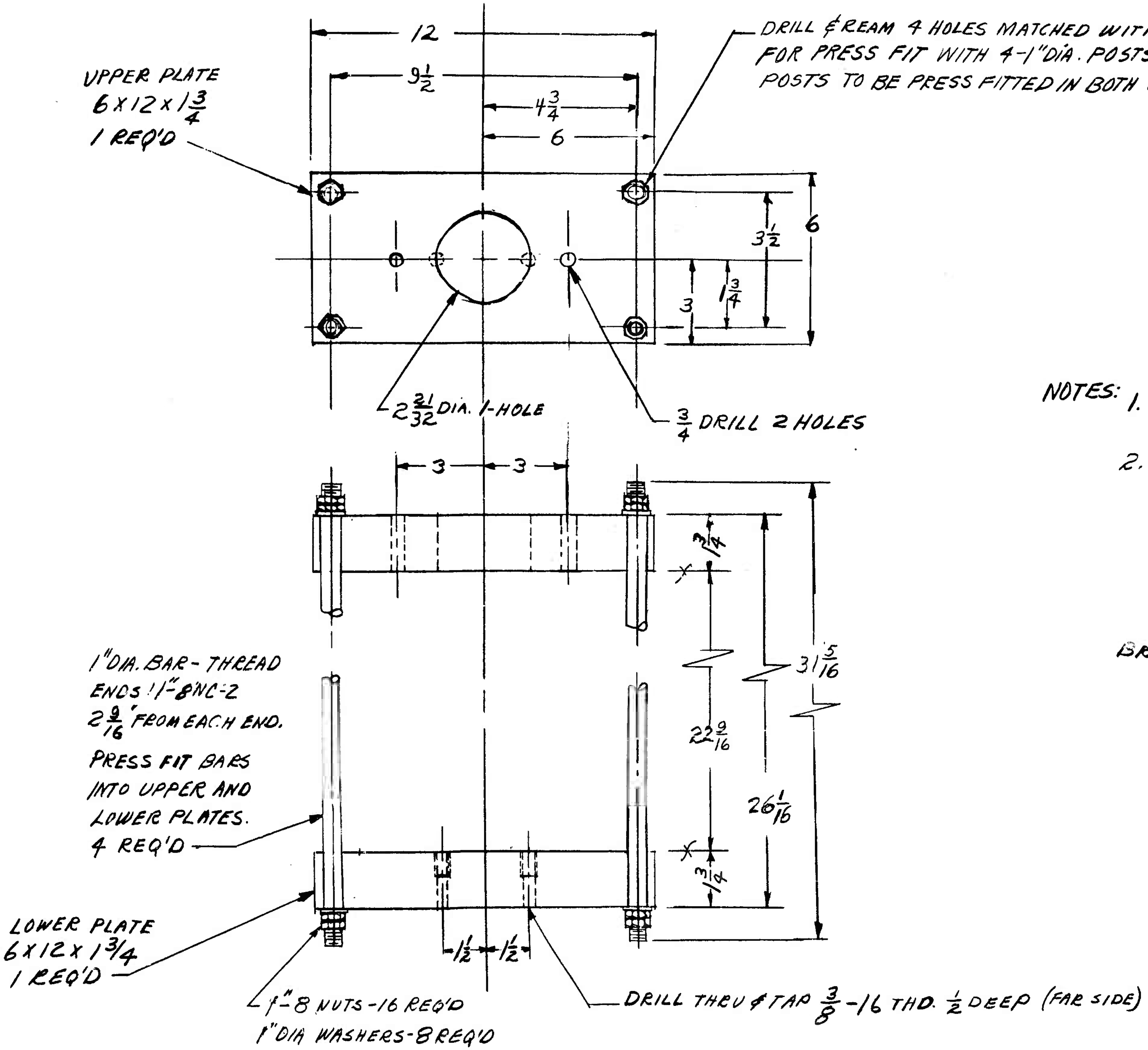


FIGURE 5.
DETAILS ON INITIAL DESIGN OF HYDRAULIC TEST FIXTURE
NOTE: SUPERSEDED BY LENGHENED CHAMBER DESIGN, SEE ASSEMBLY, FIGURE 7.



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LET.	DATE	DESCRIPTION OF CHANGE	APPROVED
AMERICAN MACHINE & FOUNDRY CO.			
TRADE MARK	PART NAME	FIGURE 6. LOADING FRAME	

NOTES:
1. INSIDE FACES OF UPPER AND LOWER PLATES TO BE ASSEMBLED PARALLEL TO HOLD $22\frac{9}{16}$ DIM.
2. ALL MATERIAL TO BE STEEL.

BREAK SHARP EDGES .005R

HYDRAULIC TEST FIXTURE

AMERICAN MACHINE & F'DRY
1104 S. WABASH. CHICAGO
DRAWN BY A. KARBIN 5-16-55
SCALE ≈ 1/4 SIZE
1027-51-0001

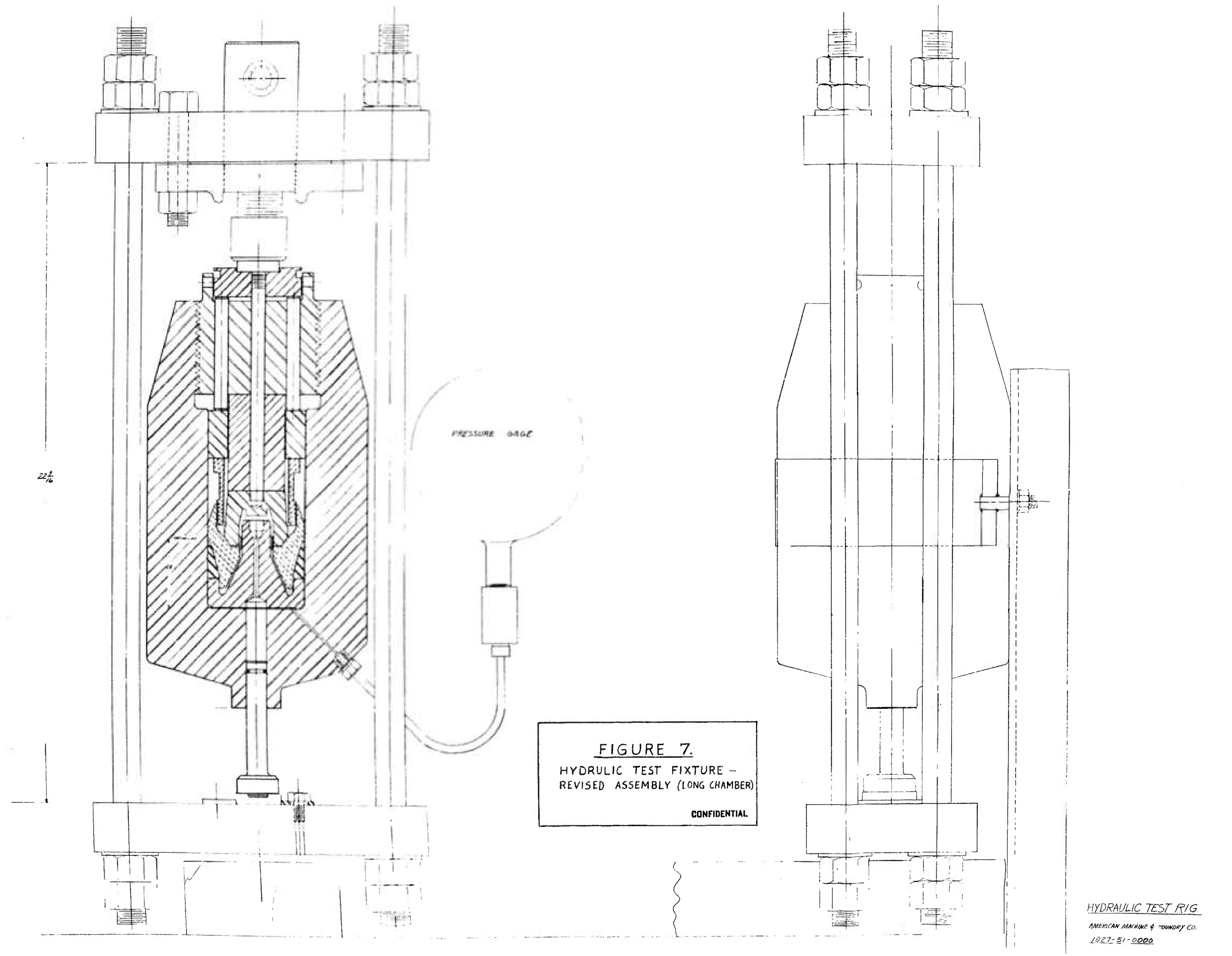

FIGURE 7.
HYDRULIC TEST FIXTURE – REVISED ASSEMBLY (LONG CHAMBER)

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